

# **Process Specification for Automatic and Machine Arc Welding of Steel and Nickel Alloy Hardware**

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**Engineering Directorate**

**Structural Engineering Division**

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National Aeronautics and  
Space Administration

**Lyndon B. Johnson Space Center**  
Houston, Texas

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# **Process Specification for Automatic and Machine Arc Welding of Steel and Nickel Alloy Hardware**

**Prepared by :**      **Signature on file**      **2/28/06**  
                                  Daniel J. Rybicki      Date  
                                  Materials and Processes  
                                  Branch/ES4

**Approved by:**      **Signature on file**      **3/07/06**  
                                  Bradley S. Files,      Date  
                                  Chief  
                                  Materials and Processes  
                                  Branch/ES4

REVISIONS		
VERSION	DESCRIPTION	DATE
Baseline	Original version	6/1/95
A	Formatting, changed process owner, elimination of subclasses and types, deleted requirement for WIR, refers to ASTM specs E1417 and E1742, refers to heat treat PRCs, included and expanded acceptance criteria, deleted section 8.2 on audits, rewrote numerous sections for clarification.	07/29/99
B	Allow for flight and non flight hardware. Numerous editorial corrections. Include requirements for precision cleaned hardware (ref. JPG 5332.1). Rewrite definitions for weld classes. To match that of PRC-0005.	02/06/2004
C	Correct 2 typographical errors where it was found a reference to PRC-0005 and should be PRC-0010. Changed reference to SOP-004.5 from EM-004.5.	02/16/2006

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## 1.0 SCOPE

This process specification provides the minimum requirements that govern the automatic and machine arc welding of steel and nickel alloy hardware. Procedural and quality assurance requirements are given. All Detailed Process Instructions (DPI) and Weld Procedure Specifications (WPS) used during welding shall satisfy the requirements of this process specification and its applicable documents.

## 2.0 APPLICABILITY

This specification applies to the automatic and machine arc welding of carbon and alloy steels, stainless and corrosion resistant steel alloys, and nickel alloy hardware fabricated under the authority of the NASA/Johnson Space Center (JSC).

This process specification applies to arc welding of carbon and alloy steels, stainless and corrosion resistant steel alloys, and nickel alloy hardware that is fabricated under the authority of NASA/Johnson Space Center (JSC) by any of the following types of welding processes:

- a. Gas tungsten arc welding (GTAW).
- b. Plasma Arc Welding (PAW).

The term "flight hardware" refers to any hardware used as a part of a spacecraft, aircraft, or payload. The term "ground based hardware" refers to any hardware made for facilities (buildings and related accessories), ground support equipment, training and mockup mission equipment, engineering prototype and development hardware, and test equipment.

## 3.0 USAGE

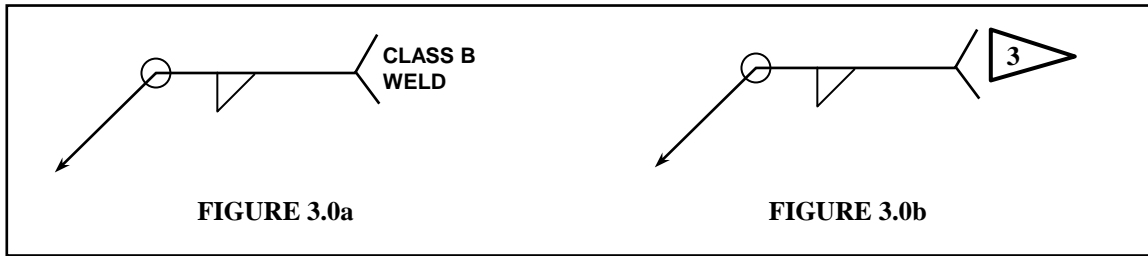
This process specification shall be invoked by including a note on the applicable engineering drawing with the following general format which specifies the PRC and weld class nomenclature:

<b>WELD AND INSPECT PER NASA/JSC PRC-0010, CLASS X.</b>
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To minimize fabrication costs by avoiding over-inspection and unnecessary rework/repair, individual welds, or components on a weldment shall be classified separate where possible. This can be accomplished by including a note on the engineering drawing with the general format shown below which specifies only the PRC nomenclature. The weld class shall then be indicated by either: 1) calling out the specific weld class with the welding symbol at the individual weld joints or, 2) by using specific flag notes with the welding symbol at the individual weld joints. Refer to Figure 3.0a and 3.0b below for examples of these methods.

<b>WELD AND INSPECT PER NASA/JSC PRC-0010. WELD CLASSES SHALL BE AS INDICATED AT WELD LOCATION CALLOUTS.</b>
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### 3.1 WELD CLASSIFICATION

Welds made using this specification shall be primarily classified in accordance with the service conditions of the weldment. The "Class" governs the extent to which quality assurance provisions are applied to the weld joint.

Alternatively, individual welds, welded connections, or entire weldments (for simplicity, the terms weld, welded connection, and weldment will be used interchangeably) may be classified by relating the weld to the factor of safety used in the design. However, when classifying welds in this manner, regardless of the factor of safety, adequate consideration should be given to the severity of the service conditions (e.g., static loading vs. dynamic loading, cyclic, vibration, fatigue, corrosive, extreme temp, etc.), material characteristics (e.g., ductility, toughness, etc.), and the potential consequences of weld failure.

Where conditions exist that make it difficult to choose between 2 weld classes, then the more stringent of the 2 classes shall be applied.

Quality assurance provisions for all weld classes are detailed in Section 7.0. Weld classes shall be chosen on the basis of the following definitions:

- a. Class A (Flight or non flight) — Applies to welds in critical load bearing elements that are not fail-safe. Class A welds are typically used in primary load bearing connections. Failure of a Class A weld in service would be catastrophic and would result in the loss of life, system(s), control, or major components. Alternatively, if it is determined from appropriate engineering analyses that a weld has a Factor of Safety (FSuts) vs ultimate tensile strength of the calculated minimum weld throat cross section of  $<2.0$ , it shall be designated as a Class A weld.
- b. Class B (Flight or non flight) — Applies to welds in load bearing elements that are fail-safe. Class B welds are typically used in secondary load bearing (i.e., shared load) connections. Failure of a Class B weld in service would reduce the overall efficiency of the system, but the loss of the system(s) or endangerment to personnel would not be expected. Alternatively, if it is determined from appropriate engineering analyses that a weld will have a FSuts of  $\geq 2.0$  and  $<3.5$ , it may be designated as a Class B weld.
- c. Class C (Flight or non flight) — Applies to welds that are in minor load bearing elements that are fully contained where failure in service would have minor or no affect on the efficiency of a system and endangerment

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to personnel would not occur. Class C welds are typically used in secondary or tertiary load bearing (i.e., shared load) connections. Alternatively, if it is determined from appropriate engineering analyses that a weld will have a FSuts of  $\geq 3.5$  and  $< 5.0$ , it may be designated as a Class C weld.

In addition to the above definitions, the following requirements shall also apply to weld classifications:

- If any weld intersects or overlaps another weld of a higher classification, then the lower classed weld shall be automatically upgraded to the higher of the 2 weld classes and subjected to the appropriate quality assurance provisions.
- If any weld falls within  $\frac{1}{2}$ " of any higher classed weld, then it shall be automatically upgraded to the higher of the 2 weld classes and subjected to the appropriate quality assurance provisions.

### **3.2 WORK INSTRUCTIONS**

Work instructions shall be generated for implementing this process specification. The work instructions shall contain sufficient detail to ensure that the manufacturing process produces consistent, repeatable products that comply with this specification. At JSC, these work instructions are approved as Detailed Process Instructions (DPIs) that describe in a detailed, step-by-step format the required procedures, equipment, and materials to be used for conducting a given process.

If this manufacturing process is to be performed by an outside vendor, work instruction development shall be the responsibility of the vendor. The contractor shall ensure that the work instructions meet the requirements of this process specification.

### **3.3 DESIGN REQUIREMENTS**

- a. The design of welded joints (including weld sizes) shall utilize adequate engineering analysis methods (e.g., stress analysis, fracture mechanics/fracture control, etc.) to ensure that the resultant connection strength is capable of successfully transferring the maximum load expected to pass between the interconnecting members and meet the required factors of safety and design margins.
- b. All engineering drawings shall depict welded joints using the applicable symbols described in AWS A2.4.
- c. The engineering drawing shall specify any additional or alternate testing or inspection requirements. Where spot, intermittent, or other special inspection requirements are specified that deviate from those stated herein, it shall be detailed on the drawing as a note or by using the applicable symbology described in AWS A2.4. For Class A welds, alternate or reduced NDE requirements shall not be allowed.
- d. Class A welds are expected to be welds requiring full strength of the weld joint therefore, these welds shall be a groove design and full penetration

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wherever possible. The ability to successfully perform radiographic examination on these weld joints shall be considered during design.

- e. Class A welds which will be subjected to unusual or extreme service conditions (e.g., severe dynamic loading, cyclic, vibration, impact, corrosive, fatigue, extreme temp, etc.), shall be welded using a WPS qualified in accordance with AWS B2.1 "Special Test Weldments." This requirement shall be noted on the engineering drawing.
- f. Unless otherwise specified on the engineering drawing or WPS, welded hardware will be delivered in the "as welded" condition. If required, any heat treatment processing required shall be detailed on the engineering drawing and shall include notation that will reference NASA/JSC PRC-2001 or PRC-2003 as applicable.
- g. Intermittent welding (skip welds) shall not be specified for Class A welds.
- h. Intermittent welds shall not be specified for groove welds (square or prepared groove design) unless the unwelded portions of the joint are adequately supported to prevent one member from coming out of plane with the adjoining member.

#### **4.0 REFERENCES**

The standards and documents listed below shall be considered a part of this specification to the extent specified herein. Unless otherwise indicated, the revision that is in effect on the date of invitation for bids or the date of request for proposals shall apply.

##### **a. American Society of Nondestructive Testing (ASNT)**

SNT-TC-1A            *Personnel Qualification and Certification in Nondestructive Testing*

##### **b. American Welding Society (AWS) Standards**

ANSI/AWS A2.4        *Standard Symbols for Welding, Brazing and Nondestructive Testing*

ANSI/AWS A3.0        *Standard Welding Terms and Definitions*

ANSI/AWS A5.9        *Specification for Bare Stainless Steel Welding Electrodes and Rods*

ANSI/AWS A5.12      *Specification for Tungsten Arc Welding Electrodes*

ANSI/AWS A5.14      *Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rods*

ANSI/AWS A5.18      *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*

ANSI/AWS A5.28      *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding*

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ANSI/AWS B2.1      *Standard for Welding Procedure and Performance Qualification*

ANSIAWS QC-1      *Standard for AWS Certification of Welding Inspectors*

**c.      Compressed Gas Association, Inc.**

G-11.1              *Argon, Commodity Specification for*

**d.      Military Documents**

MIL-A-18455        *Argon, Technical*

MIL-P-27407        *Propellant Pressurizing Agent, Helium*

MIL-P-27201        *Military Specification, Propellant, Hydrogen*

**e.      NASA/JSC Documents**

JPG 5322.1        *Contamination Control Requirements Manual*

PRC-2001           *Process Specification for the Heat Treatment of Steel Alloys*

PRC-2003           *Process Specification for the Heat Treatment of Nickel Alloys*

PRC-6503           *Process Specification for Radiographic Inspection*

PRC-6504           *Process Specification for the Ultrasonic Inspection of Wrought Metals*

PRC-6505           *Process Specification for Magnetic Particle Inspection*

PRC-6506           *Process Specification for Liquid Penetrant Inspection*

SOP-004.5        *Control of Weld Filler Materials, Electrodes, and Fluxing Materials*

SOP-007.1        *Preparation and Revision of Process Specifications*

TI-0000-04        *Training For Welders and Welding Operators*

**f.      SAE / AMS Documents**

AMS-STD-1595      *Qualification of Aircraft, Missile and Aerospace Fusion Welders*

**5.0      MATERIAL REQUIREMENTS**

All materials (base and filler materials as applicable) used in the welding of hardware per this specification, shall meet the requirements of an applicable JSC material specification unless otherwise specified. If a JSC material specification is not available, then an applicable commercial specification or a manufacturer's specification shall be used.

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## 5.1 SHIELDING GASES

Allowable shielding gases (including purge gases) are listed in Table I. Gases purchased to alternate specifications shall be allowed provided they meet the minimum requirements of the specifications listed herein. Mixtures of these gases are allowed and the nominal mixture used for the qualification welding shall be that used for production and shall be listed on the WPS. Shielding and purging gas mixtures shall be subject to the qualification variable requirements listed in AWS B2.1. In addition:

- a. Hydrogen gas in any concentration, may not be used for welding any alloys known to be susceptible to hydrogen related problems (e.g., alloy steels, Q&T steels, martensitic stainless steels, etc.).
- b. Nitrogen shall not be used for shielding or purging in any welding operation governed under this specification.
- c. All gases used for shielding or purging shall have a dewpoint of -40°F (minus 40 °C) or better.

## 5.2 FILLER METALS AND ELECTRODES

All filler metals shall meet the requirements of the applicable AWS filler metal specification relative to the specific alloy and process being used. Filler metals shall be selected from Tables II, III, and IV. If designated in **BOLD TYPE**, this shall be the first choice for filler metal. Otherwise, selection shall be based on specific base metal combinations, service environment, etc.). Tubular sleeve and filler insert materials shall have compositions similar to those indicated in Tables II, III, and IV. In addition, the following shall apply:

- a) For dissimilar metal welds joining carbon steel to low alloy steel, or between two different low alloy steels, filler metal with strength levels matching the lower strength material shall be used. For dissimilar metal joints involving stainless and corrosion resistant steels, nickel alloys, and/or other materials, filler metal selection shall be based on that stated herein and approved by the NASA/JSC M&P organization prior to use.
- b) All filler metals shall be used in accordance with a qualified WPS.
- c) Filler metal configurations which can not be procured to an AWS or other applicable filler metal specification shall meet an applicable NASA/JSC or other industry material specification and shall be approved by the NASA/JSC M&P organization prior to use.
- d) Non consumable tungsten and tungsten alloy electrodes for GTAW and PAW shall conform to the applicable AWS specification.
- e) Filler metals shall be listed on the engineering drawing.

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**Table I. Allowable Shielding Gases**

<b>GAS</b>	<b>DESCRIPTION</b>	<b>SPECIFICATION</b>
Argon	Gas	MIL-A-18455
Argon	Type II, Grade B (Liquefied)	CGA G-11.1
Carbon Dioxide	Grade B	BB-C-101
Helium	Type I, Grade A	MIL-P-27407
Hydrogen	Gas	MIL-P-27201
Oxygen	Type I	BB-O-925

**Table II. Approved Filler Metals for Welding Carbon and Low Alloy Steel**

<b>MATERIAL GROUP</b>	<b>SMAW</b>	<b>GTAW / GMAW and PAW</b>	<b>FCAW</b>
<b>M-1</b>	A5.1: E60XX, <b>E70XX</b> or A5.5: E70XX-A1 <sup>(a)</sup>	A5.28: E70S-2, E70S-3, <b>E70S-6</b>	A5.22: <b>E70T-1</b> , E70T-5
<b>M-3</b>	A5.5: E70XX-A1	A5.28: <b>ER80S</b> / E80C-D2	(b)
<b>M-4</b>	A-5.5: E80XX-B2	A5.28: <b>ER80S</b> , E80C-B2, ER80S / E80C-B2L	(b)
<b>M-5</b> (3% Cr max)	A5.5: E90XX-B3	A5.28: <b>ER90S</b> , E80C-B3, ER90S / E90C-B3L	(b)

Notes:

- (a) A5.5, E70XX-A1 shall be used for materials with maximum specified carbon greater than 0.30%.
- (b) Filler metal to be used for joining must be compositionally compatible with base metal. Primary consideration shall be given to mechanical properties, corrosion resistance, and weldability, as applicable for the specific application.
- (c)

**Table III. Approved Filler Metals for Welding Nickel Alloys**

<b>BASE METAL</b>	<b>SMAW (AWS A5.11)</b>	<b>GTAW / GMAW / PAW (AWS A5.14)</b>
<b>Nickel 200</b>	ENi-1	ERNi-1
<b>Nickel 201</b>		
<b>Monel 400</b>	ENiCu-7	ERNiCu-7
<b>Monel K500</b>	--	ERNiCu-7
<b>Inconel 600</b>	<b>ENiCrFe-1</b> , ENiCrFe-3	<b>ERNiCrFe-5</b> , ERNiCr-3
<b>Inconel 601</b>	<b>ENiCrFe-3</b> , ENiCrMo-3	<b>ERNiCr-3</b> , ERNiCrMo-3
<b>Inconel 625</b>	ENiCrMo-3	ERNiCrMo-3
<b>Inconel 718</b>	--	ERNiFeCr-2
<b>Inconel X750</b>		
<b>Incoloy 800</b>	<b>ENiCrFe-2</b> , ENiCrCoMo-1	<b>ERNiCr-3</b> , ERNiCrCoMo-1
<b>Incoloy 800HT</b>	ENiCrFe-2	ERNiCr-3
<b>Incoloy 825</b>	--	ERNiFeCr-1

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**Table IV. Approved Filler Metals for Welding Austenitic Stainless Steel**

<b>AWS M-8 Base Metal:</b>	<b>304 308</b>	<b>304L</b>	<b>309</b>	<b>310</b>	<b>316</b>	<b>316L</b>	<b>321 347 348</b>
<b>301 302 304 308</b>	308 <b>308L</b>	308 <b>308L</b>	308 308L 309 <b>309L</b>	308 308L 309 <b>309L</b> 310	308 308L 316 <b>316L</b>	308 308L 316 <b>316L</b>	308 <b>308L</b>
<b>304L</b>	308 <b>308L</b>	<b>308L</b>	308 308L 309 <b>309L</b>	308 308L 309 <b>309L</b> 310	308 308L 316 <b>316L</b>	308L <b>316L</b> 309L	<b>308L</b> 347
<b>309</b>			309 <b>309L</b>	309 <b>309L</b> 310	309 309L 316 <b>316L</b>	309 309L 316 <b>316L</b>	309 <b>309L</b> 347
<b>310</b>				310	316 <b>316L</b> 310	316 <b>316L</b> 310	308 308L <b>310</b>
<b>316</b>					316 <b>316L</b>	316 <b>316L</b>	308 308L 316 <b>316L</b>
<b>316L</b>						309L <b>316L</b>	309L <b>316L</b>
<b>321 347 348</b>							309L 321 <b>347</b>

### 5.2.1 Control and Storage

Welding electrodes shall be stored in a clean, dry, and controlled area that provides protection from contamination, physical damage, and commingling of alloys. Any form of electrodes or weld filler metal which is damaged, dirty, exhibits oxidation/corrosion or has been contaminated with water, oil, grease or any form of hydrocarbons shall not be used and shall be disposed of in accordance with an appropriate disposal procedure. For JSC operations, welding electrodes and filler materials shall be controlled in accordance with SOP-004.5. Outside vendors shall provide control and storage according to the applicable material specification or manufacturer's recommendation, whichever is more rigid.

## 6.0 PROCESS REQUIREMENTS

All weldments shall be fabricated according to the requirements of this process specification. The requirements of the applicable codes and standards listed in Section

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4.0, shall be met as specified by this PRC based on the design and intended function of the hardware. Certain paragraphs of this process specification are abbreviated re-statements taken from the applicable standards and are included here for the user's convenience. The remaining paragraphs of this process specification represent requirements imposed in addition to the basic requirements of the applicable codes and standards.

All arc welding shall be performed using Welding Procedure Specifications (WPS) that have been qualified in accordance with the requirements of Section 6.2. To accommodate any unique differences due to tooling, fixtures, grounding, etc. in the weld parameter settings between a test specimen welding condition and a production component welding condition, a one time adjustment to the heat input specific parameters shall be allowed with no additional qualification testing required. This adjustment in setting(s) shall be allowed on the "first production component" only. The specific changes shall be documented on a revised WPS reflecting the statement "First Production Component Adjustment" to differentiate from the original WPS.

#### **6.1 WELDING PRECISION CLEANED HARDWARE (including tube preparation for welding)**

Whenever precision-cleaned hardware must be maintained clean during welding into an assembly, the welding operation shall be performed in a dedicated Class 100,000 Clean Work Area. This may require temporary tents over the weld area and/or local monitors located in the area of welding to ensure the Class 100,000 environment is being met. Portable particle counters shall be located as close as possible to the work area, so as to monitor local contaminants during tube preparation and welding. Tools used in weld preparation and welding (such as cutter, weld head, files) shall be visibly cleaned per JPG 5322.1 and maintained clean (e.g. bagged when not in use).

For hardware that cannot be subsequently precision-cleaned, a proven method for protecting against system contamination during tube preparation and welding shall be implemented. One such method is the use of a physical barrier, such as plugs. The installation and removal of plugs shall be tracked by a reliable method and independently verified. Prior to plug removal, the exposed internal surfaces of the tube shall be cleaned using a swab wetted with an approved solvent, and positive backpressure shall be maintained as the plug is removed.

Tube cutters shall use a sharp blade, changed frequently. Cutting shall be performed with minimal cutter pressure to aid in preventing particle generation. Vacuum shall be used during tube facing operations to remove particulate. Whenever possible, facing operations shall be performed away from the weld assembly area, to reduce particulate contamination of the welding work area. Tube facing shall be performed without the use of cutting oils, other fluids, lubricants or coolants. Abrasives, including sandpaper or abrasive pads, shall not be used inside tubes or when unprotected internal surfaces are exposed. After each tube preparation, and prior to welding, a high-velocity gas purge shall be performed. The purge gas velocity shall be the maximum attainable using a 90-psig source. The purge gas used during facing and welding shall meet the hydrocarbon and particulate requirements for the system under assembly. The purge gas shall be supplied in accordance with Section 5.1.

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## **6.2 PROCESS-SPECIFIC REQUIREMENTS**

### **6.2.1 Gas Tungsten Arc Welding**

Additional filler metal shall be used with the GTAW process unless it can be demonstrated by weld qualification that weld cracking and other undesirable metallurgical conditions will not exist in the finished weld made without filler metal (autogenous weld). This method of welding shall be specified on an approved WPS.

### **6.2.2 Plasma Arc Welding**

Additional filler metal shall be used with the PAW process unless it can be demonstrated by weld qualification that weld cracking and other undesirable metallurgical conditions will not exist in the finished weld made without filler metal (autogenous weld). This method of welding shall be specified on an approved WPS.

## **6.3 WELD QUALIFICATION**

This specification provides specific allowances for components that are fabricated for pressure containing applications and non pressure containing (i.e., structural only) applications.

### **6.3.1 Pressure Containing Components**

A Welding Procedure Specification (WPS) shall be qualified for each unique weld type (as detailed in 6.2.1.1) to be produced, before the production welds are made. An existing qualified WPS for one unique weld type may be used for a different engineering drawing provided the requirements of 6.2.1.1 are met, and it is demonstrated that the essential weld variables listed in Table V will be met. Demonstration shall constitute all the requirements of Section 6.2.3 except that no additional documentation is required except, when a WPS(s) is written for a specific item(s) of hardware, it shall be revised/amended to show allowance for use on other than the initial specifically stated hardware. The actual welding variables, methods, practices, specific tooling requirements, and test results used during WPS qualification shall be recorded on a Procedure Qualification Record (PQR).

#### **6.3.1.1 Unique Weld Type**

A "Unique Weld Type" includes those weld joint configurations that differ from one another in any of the following respects:

1. Base material thickness,
2. Base material type (M-number/alloy),
3. Square groove joint vs. bevel, V, or U-groove joints,
4. Groove joint vs. fillet weld,
5. Addition or deletion of filler material,
6. Addition, deletion, or change in the Preheat, Interpass, or Post Weld Heat Treat (PWHT) requirements.

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### 6.3.1.2 Test Requirements

At a minimum, the following are minimum requirements for the qualification of a welding procedure. This effort shall include the welding of a minimum of 9 weld samples that represent the weld type specified. Three of these welds shall be made at a “nominal” heat input setting, 3 shall be made at a “limit low” heat input setting, and 3 shall be made at a “limit high” heat input setting. All samples shall be visually inspected on the O.D. and I.D. to Class A criteria and radiographically inspected to Class A criteria. If the weld procedure includes a PWHT, the radiographic inspection shall, at a minimum, be performed after the PWHT cycle. Two samples from each group shall be mechanically tested in tension and the results evaluated to the requirements of AWS B2.1. One sample from each group shall be sectioned and metallographically examined and the results evaluated to the requirements of AWS B2.1. Photomicrographs shall be taken of the prepared samples and retained with the PQR.

### 6.3.1.3 Essential Variables

The WPS shall specify all of the essential welding variables and the applicable allowable ranges qualified for each variable, as indicated in Table V. In addition, the WPS shall detail all methods, practices, specific tooling requirements that are determined necessary by the operating facility to successfully execute the weld in production.

Table V - Essential Welding Variables

Variable #	Variable / Weld Type	Range Allowed
1	Power Source Model #	None
2	Weld Head Model #	None
3	Joint Configuration	None
4	Groove Angle	+/- 5°
5	Nominal Tube Dia.	None
6	Nominal Wall Thickness	None
7	Material Type(s)	None
8	Electrode Start Position	+/- 60°
9	Preweld Cleaning Steps	None
10	Allowable Joint Gap	None
11	Tool or Shop Aid Identification	None
12	Preweld Purge Time	(1)
13	Postweld Purge Time	(1)
14	Tube ID Prepurge Flow Rate or Pressure	None
15	Weld Head Prepurge Flow Rate	+/- 15%
16	Plasma Gas Flow Rate	+/- 10%
17	Gas Composition/Spec.	None
18	Electrode Travel Speed & Machine Setting	None
19	Arc Travel Start Delay	None
20	Total Weld Current On Time	None
21	Weld Time @ Level or Circumference Interval	None
22	Current Pulse Width (%)	None
23	Current Pulse Rate	None
24	Filler Material / Spec.	None

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Variable #	Variable / Weld Type	Range Allowed
25	Filler Wire Feed Speed	+/- 50%
26	Consumable Insert Type and Specification	None
27	Tubular Sleeve Spec.	None
28	Background Welding Current	None
29	Pulse Welding Current	None
30	Electrode Type	None
31	Electrode Diameter	None
32	Electrode Tip Geometry	None
33	GTAW Electrode to Work Gap (nom. setting)	+/- 10%
34	PAW Electrode Position Setting (nom. setting)	+/- 10%
35	PAW Orifice Size	None
36	Minimum Preheat Temp.	None
37	Maximum Interpass Temp.	None
38	PWHT Procedure/Spec.	None

### **6.3.2 Non Pressure Containing Piping and Tubing Components and Structural Components**

A Welding Procedure Specification (WPS) shall be qualified for each unique weld type (as detailed in 6.2.2.1) to be produced by conforming to the requirements below, before the production welds are made. An existing qualified WPS for one unique weld type may be used for a different engineering drawing provided the requirements of 6.2.2.1 are met, and it is demonstrated that the procedure qualification variables (essential variables) listed in AWS B2.1 will be met. Demonstration shall constitute all the requirements of Section 6.2.3 except that no additional documentation is required except, when a WPS(s) is written for a specific item(s) of hardware, it shall be revised/amended to show allowance for use on other than the initial specifically stated hardware. The actual welding variables, methods, practices, specific tooling requirements, and test results used during WPS qualification shall be recorded on a Procedure Qualification Record (PQR).

#### **6.3.2.1 Unique Weld Type**

A "Unique Weld Type" includes those weld joint configurations that differ from one another in any of the following respects:

1. Base material thickness,
2. Base material type (M-number/alloy),
3. Square groove joint vs. bevel, V, or U-groove joints,
4. Groove joint vs. fillet weld,
5. Addition or deletion of filler material,
6. Addition, deletion, or change in the Preheat, Interpass, or Post Weld Heat Treat (PWHT) requirements,
7. Addition or deletion of backing.

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### **6.3.2.2 Test Requirements**

At a minimum, the welding and testing requirements for non pressure containing tubing and piping applications, or structural applications shall conform to the requirements of AWS B2.1.

### **6.3.2.3 Essential Variables**

The WPS shall specify all of the essential welding variables as indicated in AWS B2.1 and the applicable allowable ranges qualified for each variable, as specified in AWS B2.1. In addition, the WPS shall detail all methods, practices, specific tooling requirements that are determined necessary by the operating facility to successfully execute the weld in production.

### **6.3.3 REQUALIFICATION OF WPS**

Requalification of the WPS shall be required when any of the following conditions exist:

- a) The weld system has been placed on a different external power source except when the power supply has a means for internal power regulation,
- b) Major maintenance has been performed on the weld system. Major maintenance includes replacement of the power supply, major repair of the power supply requiring entrance into the controller welding power supply, or replacement of the weld head has occurred,
- c) Preproduction weld samples do not meet requirements and no assignable cause for the failure can be determined.

Requalification may be performed with less total test sample requirements than that required for an initial qualification for a unique weld type. For requalification, only 2 weld samples shall be produced and submitted; one at the "high limit" setting and one at the "low limit" setting for that WPS. Requalification due to item a) or b) above only requires weld samples to be made from one WPS that is specified for use on that system.

The samples shall, at a minimum, be subjected to visual inspection and volumetric NDE and shall meet the applicable requirements specified herein. Requalification results shall be documented on a PQR with a specific notation made indicating "Requalification" and an explanation as to the cause. If the requalification activities result in any welding parameter(s) deviations that exceed the range specified in Table V or AWS B2.1 as applicable, for that parameter, then the level of testing in 6.2.4 shall be required.

## **6.4 PREHEATING**

Preheat shall not exceed the temperature specified in the applicable WPS. In weld joints between different base metal types and thickness, the higher of the preheat requirements of the joint members shall apply.

## **6.5 INTERPASS TEMPERATURE**

- a. In weld joints between different base metal types and thickness, the higher of the preheat requirements of the joint members shall apply.

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- b. Minimum interpass temperature during welding shall be the same as the minimum preheat temperature specified in the welding procedure specification and shall be maintained by the application of concurrent heat if necessary.
- c. The maximum interpass temperature for welding quenched and tempered steels shall be at least 50° F below the nominal tempering temperature and is limited to this temperature in order to ensure adherence to the steel manufacturer's recommendations regarding heat input.

## 6.6 POST WELD HEAT TREATMENT (PWHT)

Postweld heat treatment, when required by the engineering drawing or WPS, shall be performed after completion of all welding in accordance with NASA/JSC PRC-2001 or PRC-2003, as applicable. Vibratory techniques shall not be used in place of thermal treatments.

## 6.7 WELD REPAIRS AND WELDED REPAIRS TO BASE METAL

All weld and welded repairs shall be performed using the WPS used for the original weld or a specific qualified WPS for that repair and shall meet all of the requirements of the original drawing and any additional requirements that are documented in the WPS. A weld repair may be applied manually in lieu of an automated or machine applied repair, provided the essential variables/parameters of the original WPS are duplicated and the heat input applied is less than the initial weld. Weld repair does not include the correction of dimensional or other deficiencies of weld joints groove/bevel preparation by "buttering" or build up provided the area corrected by welding is fully consumed in the final weld. Also, the following requirements shall be required in the weld repair activity:

- a) Defect Removal. Defect removal shall be by means of grinding, chipping, or machining, or a combination of these methods. Thermal gouging and cutting may be used on carbon and low alloy steels provided the excavated cavity is finished by grinding to sound metal. The final repair cavity shall be of a configuration suitable for welding. The excavation shall be subjected to visual and/or NDE inspections to ensure defect removal prior to welding. Weld repairs shall be adequately documented by the use of a weldment map or other manufacturing record with sufficient detail to ensure identification of the weldment, identification of repair location(s), and type of defect.
- b) Repair. No more than two weld attempts shall be made to successfully complete a welded repair. If a second attempt is unsuccessful, a discrepancy report shall be generated and shall require dispositioning by the responsible Material Review Board (MRB). The level of documentation of repair welds shall, at a minimum, be consistent with that required for the original production weld.
- c) Straightening. Welds or adjacent base metal which have been deformed by the welding operation may be straightened. All straightening operations shall take place at temperatures not to exceed 121°C (250°F). All straightening operations must be validated by an appropriate method(s) to show that the process used for straightening shall not degrade the joint or surrounding material below specified design requirements.

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- d) Base Metal Repairs. Repairs to base metal anomalies shall be brought to the attention of the NASA/JSC M&P organization for consideration of cause, prior to repair activities.

## 7.0 PROCESS VERIFICATION

Process verification shall consist of visual inspection and/or nondestructive inspection, as described further in sections 7.1 to 7.3. In addition, at the appropriate time during the fabrication activities, the following items shall be verified:

- a) Verify that the welder is certified for the specific welding operation (prior to welding).
- b) Fit-up in accordance with the engineering drawing (prior to welding for Class A Pressure Containing Components).
- c) A WPS exists (prior to welding).
- d) Compliance with WPS for essential variable ranges (during welding).
- e) PWHT in accordance with the assigned WPS (after welding).

## 7.1 INSPECTION

### 7.1.1 Class A Inspection - Pressure Containing Components

- a) Unless otherwise specified, Class A joints require visual inspection and volumetric inspection using either the radiographic method or ultrasonic method to the Class A acceptance criterias in Appendix A.
- b) In cases where the Class A inspection is designated for a fillet joint, or for any joint having a configuration which renders radiography or ultrasonics an impractical method, an alternate inspection method shall be utilized with approval from the responsible NASA/JSC M&P organization.
- c) When the liquid penetrant or magnetic particle method is selected as an alternate to volumetric inspection for multipass welds, inspections shall be performed on the root pass, each  $\frac{1}{4}$ " thick layer of weld metal, and the final or cover pass.

#### 7.1.1.1 Class A Inspection - Non Pressure Containing Piping and Tubing Components and Structural Components

- a) Unless otherwise specified, Class A joints require visual inspection and volumetric inspection using either the radiographic method or ultrasonic method to the Class A acceptance criterias in Appendix B.
- b) In cases where the Class A inspection is designated for a fillet joint, or for any joint having a configuration which renders radiography or ultrasonics an impractical method, an alternate inspection method shall be utilized with approval from the responsible NASA/JSC M&P organization.
- c) When the liquid penetrant or magnetic particle method is selected as an alternate to volumetric inspection for multipass welds, inspections shall be

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performed on the root pass, each ¼" thick layer of weld metal, and the final or cover pass.

### **7.1.2 Class B Inspection - Pressure Containing Components**

Unless otherwise specified in design documentation, Class B joints require visual inspection and liquid penetrant or magnetic particle inspection to the Class B acceptance criterias in Appendix A.

#### **7.1.2.1 Class B Inspection - Non Pressure Containing Piping and Tubing Components and Structural Components**

Unless otherwise specified in design documentation, Class B joints require visual inspection and liquid penetrant or magnetic particle inspection to the Class B acceptance criterias in Appendix B.

### **7.1.3 Class C Inspection - Non Pressure Containing Piping and Tubing Components and Structural Components**

Unless otherwise specified in design documentation, Class C joints require visual inspection to the Class C acceptance criteria in Appendix B.

## **7.2 VISUAL INSPECTION REQUIREMENTS**

All visual inspections of welded joints shall be performed by an American Welding Society (AWS) Certified Welding Inspector (CWI) qualified in accordance with AWS QC-1. The CWI certification must be current.

## **7.3 NON-DESTRUCTIVE EVALUATION (NDE)**

The NDE of welded joints shall be performed by personnel qualified in accordance with the requirements of the applicable NDE process specification. The NDE certification must be current. All nondestructive inspections shall be performed in accordance with the appropriate standards as referenced herein.

## **8.0 PROCESS DOCUMENTATION REQUIREMENTS**

The WPS, PQR, and WOPQ shall be prepared and retained as a permanent record and made available upon request to the NASA/JSC M&P organization for review. These procedures must contain, at a minimum, all of the essential welding parameters, an identification of the welding equipment, and include any pertinent tooling information. One copy of the WPS shall be maintained in the vicinity of the welding station and shall be readily accessible by the welders, inspectors, supervision, and engineering.

## **8.1 WELDING PROCEDURE SPECIFICATION**

A Welding Procedure Specification (WPS) is a qualified written working procedure that must be developed before beginning production for each unique weld type to be produced. Qualification support documentation in the form of a Procedure Qualification Record (PQR) shall be maintained on file to show proof of process/procedure capability using the WPS. The WPS shall be traceable by means of serialized nomenclature and shall show traceability to the applicable PQR(s). The WPS used for production welding

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shall meet the requirements stated herein and shall be certified by the responsible M&P organization at the operating facility, prior to use in production. "Prequalified" or "Standard Welding Procedure Specifications" shall not be permitted for production use on Class A or B welds made on flight hardware.

## **8.2 PROCEDURE QUALIFICATION RECORD**

A Procedure Qualification Record (PQR) is documentation to support the welding procedure specification to show proof of process/procedure capability. A PQR shall be unique and traceable, by means of serialized nomenclature. The PQR shall be process-specific and specific to a unique weld type. Data required in the PQR shall include detailed descriptions of the test coupon configurations and joint designs, all pertinent material specifications, all pertinent essential process variables used, all destructive and nondestructive test results from the qualification sample set, and all required certifications from the approving organization. The PQR shall be approved by the responsible M&P organization at the operating facility.

## **8.3 WELDING OPERATOR PERFORMANCE QUALIFICATION**

A Welding Operator Performance Qualification (WOPQ) is documentation that shows that a welding operator has been tested in accordance with AMS-STD-1595 and shown competent to produce a sound weld for a specific welding process/base material/base metal thickness combination.

## **8.4 DEVIATIONS AND WAIVERS**

Any deviations or waivers regarding the use of this process specification shall be requested in writing by the outside vendor. This request shall be directed to the NASA/JSC M&P organization with the appropriate justification and rationale. A written response will be provided upon such a request.

## **9.0 TRAINING AND CERTIFICATION OF PERSONNEL**

### **9.1 TRAINING**

At JSC, if welder training is considered necessary prior to qualification/requalification of existing JSC welding personnel or the initial qualification of new hires, it shall be conducted in accordance with TI-0000-04. For an outside JSC vendor, welder training (when necessary) should consist of practice using the facility welding equipment and a specific WPS to demonstrate proficiency, under the supervision of a qualified/certified welder. Specific development of an appropriate training program shall be the responsibility of the vendor.

### **9.2 WELDING OPERATOR QUALIFICATION**

Welding shall be performed by a welding operator qualified and certified in accordance with AMS-STD-1595 with the exception that mandatory 5 year requalification is not required provided the operator continuity requirement discussed below is maintained. Sufficiently detailed records shall be maintained to demonstrate continuity of operator performance on the welding system or system(s) on a semi-annual (6 month) basis. These records shall be made available to the NASA/JSC M&P organization upon request.

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## **APPENDIX A**

### **SURFACE INSPECTION ACCEPTANCE CRITERIA - CLASS A - Pressure Containing Components**

Size and Appearance of Groove Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces the base metal thickness (T) beyond the minimum specified on the drawing.
Size and Appearance of Fillet Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be flat or slightly convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces (T) beyond the minimum specified on the drawing.
Cracks	None allowed.
Undercut	Undercut shall not exceed 20% of the total weld length. The depth of any undercut indication where $T < 0.035$ ", undercut shall not exceed 5% of T. Where T is $\geq 0.035$ " and $\leq 0.09$ ", undercut shall not exceed 10% of T or 0.010", whichever is the lesser. Where $T > 0.09$ ", the depth of undercut shall not exceed 0.010". The minimum distance allowed between adjacent undercut or underbead concavity indications is 1/2 the length of the longest adjacent indication.
Pores or Voids	The maximum diameter shall not exceed 0.02" or $\frac{1}{4}$ of T, whichever is the lesser. Indications less than .010" in diameter shall not be considered.
Inadequate Penetration and Incomplete Fusion	The maximum length of any indication shall not exceed $\frac{1}{4}$ of T in any weld length of 6T or less. The minimum distance allowed between adjacent incomplete penetration or fusion indications, is $\frac{1}{2}$ the length of the longest adjacent indication.
Weld Face or Root Concavity or WM Thinning	Concavity shall not exceed 10% of T or 0.01", whichever is the lesser.
Overlap	None allowed.
Misalignment	Misalignment shall not exceed 10% of T, or 0.020", whichever is the lesser.
Peaking	Weld joint peaking shall not exceed a total of 5 degrees.
Weld Face or Root Convexity	Reinforcement, or melt-thru, shall not exceed 20% T or 0.06", whichever is the lesser.
Surface Discoloration	A black - brown color is not allowed.
Surface Roughness	Surface finish of welds and adjacent material resulting from processes used to remove weld reinforcement and otherwise shall not exceed 63 microinches.
General Workmanship	Weld deposits, face and root reinforcement and adjacent base metal shall display a smooth and uniform appearance. The weld toes shall blend smoothly into the base metal without unfused overlaps or undercut exceeding that specified.

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## **APPENDIX A**

### **SURFACE INSPECTION ACCEPTANCE CRITERIA - CLASS B - Pressure Containing Components**

Size and Appearance of Groove Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces the base metal thickness (T) beyond the minimum specified on the drawing.
Size and Appearance of Fillet Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be flat or slightly convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces (T) beyond the minimum specified on the drawing.
Cracks	None allowed.
Undercut	Undercut shall not exceed 15% of the total weld length. The depth of any undercut indication where $T < 0.035"$ , undercut shall not exceed 10% of T. Where T is $\geq 0.035"$ and $\leq 0.09"$ , undercut shall not exceed 15% of T or 0.010", whichever is the lesser. Where $T > 0.09"$ , the depth of undercut shall not exceed 0.015".
Pores or Voids	The maximum diameter shall not exceed 0.02" or 1/3 of T, whichever is the lesser. Indications less than .010" in diameter shall not be considered.
Weld Face or Root Concavity or WM Thinning	Concavity shall not exceed 15% of T or 0.015", whichever is the lesser.
Overlap	None allowed.
Misalignment	Misalignment shall not exceed 15% of T or 0.025", whichever is the lesser.
Peaking	Weld joint peaking shall not exceed a total of 5 degrees.
Weld Face or Root Convexity	Reinforcement, or melt-thru, shall not exceed 20% T or 0.06", whichever is the lesser.
Surface Discoloration	A black - brown color is not allowed.
Surface Roughness	Surface finish of welds and adjacent material resulting from processes used to remove weld reinforcement and otherwise shall not exceed 63 microinches.
General Workmanship	Weld deposits, face and root reinforcement and adjacent base metal shall display a smooth and uniform appearance. The weld toes shall blend smoothly into the base metal without unfused overlaps or undercut exceeding that specified.

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## **APPENDIX A**

### **SUB SURFACE INSPECTION ACCEPTANCE CRITERIA - CLASS A - Pressure Containing Components**

Cracks	None allowed.
Cold Shut and Laps	None allowed.
Porosity and Inclusions	The maximum diameter shall not exceed 0.02" or $\frac{1}{4}$ of T, whichever is the lesser. Indications less than .010" in diameter shall not be considered.
Inadequate Penetration and Incomplete Fusion	The maximum length of any indication shall not exceed $\frac{1}{4}$ of the base metal thickness in any weld length of 6T or less. The minimum distance allowed between adjacent incomplete penetration or fusion indications, is $\frac{1}{2}$ the length of the longest adjacent indication.
Undercut and Underbead Concavity	The length of any undercut or underbead concavity indication shall not exceed 20% of the total weld length. The depth of any undercut indication where $T < 0.035"$ , undercut shall not exceed 5% of T. Where T is $\geq 0.035"$ and $\leq 0.09"$ , undercut shall not exceed 10% of T or 0.010", whichever is the lesser. Where $T > 0.09"$ , the depth of undercut shall not exceed 0.010". The minimum distance allowed between adjacent undercut or underbead concavity indications is $\frac{1}{2}$ the length of the longest adjacent indication.
Misalignment	Misalignment shall not exceed 10% of T, or 0.020", whichever is the lesser.
Weld Face or Root Concavity or WM Thinning	Thinning shall not exceed 10% of T or 0.01", whichever is the lesser.
Weld Face or Root Convexity	Reinforcement, or melt-thru, shall not exceed 20% of T or 0.06", whichever is the lesser.

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## **APPENDIX A**

### **SUB SURFACE INSPECTION ACCEPTANCE CRITERIA - CLASS B - Pressure Containing Components**

Cracks	None allowed.
Cold Shut and Laps	None allowed.
Porosity and Inclusions	The maximum diameter shall not exceed 0.02" or 1/3 of T, whichever is the lesser. Indications less than .010" in diameter shall not be considered.
Inadequate Penetration and Incomplete Fusion	The maximum length of any indication shall not exceed 1/3 of the T in any weld length of 6T or less. The minimum distance allowed between adjacent incomplete penetration or fusion indications, is ½ the length of the longest adjacent indication.
Undercut and Underbead Concavity	The length of any undercut or underbead concavity indication shall not exceed 15% of the total weld length. The depth of any undercut indication where T < 0.035", undercut shall not exceed 10% of T. Where T is >= 0.035" and <= 0.09", undercut shall not exceed 15% of T or 0.010", whichever is the lesser. Where T > 0.09", the depth of undercut shall not exceed 0.015". The minimum distance allowed between adjacent undercut or underbead concavity indications is 1/2 the length of the longest adjacent indication.
Misalignment	Misalignment shall not exceed 15% of T, or 0.025", whichever is the lesser.
Weld Face or Root Concavity or WM Thinning	Thinning shall not exceed 15% of T or 0.015", whichever is the lesser.
Weld Face or Root Convexity	Reinforcement, or melt-thru, shall not exceed 20% of T or 0.06", whichever is the lesser.

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## **APPENDIX B**

### **SURFACE INSPECTION ACCEPTANCE CRITERIA - CLASS A -**

#### **Non Pressure Containing Piping and Tubing Components and Structural Components**

Size and Appearance of Groove Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces the base metal thickness (T) beyond the minimum specified on the drawing.
Size and Appearance of Fillet Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be flat or slightly convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces (T) beyond the minimum specified on the drawing.
Cracks	None allowed.
Undercut	Undercut shall not exceed 15% of the total weld length. The depth of any undercut indication where $T < 0.035"$ , undercut shall not exceed 10% of T. Where T is $\geq 0.035"$ and $\leq 0.09"$ , undercut shall not exceed 15% of T or 0.010", whichever is the lesser. Where $T > 0.09"$ , the depth of undercut shall not exceed 0.015".
Pores or Voids	The maximum diameter shall not exceed 0.02" or 1/3 of T, whichever is the lesser. Indications less than .010" in diameter shall not be considered.
Weld Face or Root Concavity or WM Thinning	Concavity shall not exceed 15% of T or 0.015", whichever is the lesser.
Overlap	None allowed.
Misalignment	Misalignment shall not exceed 15% of T or 0.025", whichever is the lesser.
Peaking	Weld joint peaking shall not exceed a total of 5 degrees.
Weld Face or Root Convexity	Reinforcement, or melt-thru, shall not exceed 20% T or 0.06", whichever is the lesser.
Surface Discoloration	A black - brown color is not allowed.
Surface Roughness	Surface finish of welds and adjacent material resulting from processes used to remove weld reinforcement and otherwise shall not exceed 63 microinches.
General Workmanship	Weld deposits, face and root reinforcement and adjacent base metal shall display a smooth and uniform appearance. The weld toes shall blend smoothly into the base metal without unfused overlaps or undercut exceeding that specified.

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## **APPENDIX B**

### **SURFACE INSPECTION ACCEPTANCE CRITERIA - CLASS B and C - Non Pressure Containing Piping and Tubing Components and Structural Components**

Size and Appearance of Groove Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces the base metal thickness (T) beyond the minimum specified on the drawing.
Size and Appearance of Fillet Welds	Minimum size as specified on drawing. If profile requirements are not specified on the drawing, the weld shall be flat or slightly convex with a maximum reinforcement as stated herein. Any profile is unacceptable where the weld to base metal transition forms a sharp notch or reduces (T) beyond the minimum specified on the drawing.
Cracks	None allowed.
Undercut	Undercut shall not exceed 15% of the total weld length. The depth of any undercut indication where $T < 0.035"$ , undercut shall not exceed 10% of T. Where T is $\geq 0.035"$ and $\leq 0.09"$ , undercut shall not exceed 15% of T or 0.010", whichever is the lesser. Where $T > 0.09"$ , the depth of undercut shall not exceed 0.015".
Pores or Voids	The maximum diameter shall not exceed 0.02" or 1/3 of T, whichever is the lesser. Indications less than .010" in diameter shall not be considered.
Weld Face or Root Concavity or WM Thinning	Concavity shall not exceed 15% of T or 0.015", whichever is the lesser.
Overlap	None allowed.
Misalignment	Misalignment shall not exceed 15% of T or 0.025", whichever is the lesser.
Peaking	Weld joint peaking shall not exceed a total of 5 degrees.
Weld Face or Root Convexity	Reinforcement, or melt-thru, shall not exceed 20% T or 0.06", whichever is the lesser.
Surface Discoloration	A black - brown color is not allowed.
Surface Roughness	Surface finish of welds and adjacent material resulting from processes used to remove weld reinforcement and otherwise shall not exceed 63 microinches.
General Workmanship	Weld deposits, face and root reinforcement and adjacent base metal shall display a smooth and uniform appearance. The weld toes shall blend smoothly into the base metal without unfused overlaps or undercut exceeding that specified.

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## **APPENDIX B**

### **SUB SURFACE INSPECTION ACCEPTANCE CRITERIA - CLASS A and B- Non Pressure Containing Piping and Tubing Components and Structural Components**

Cracks	None allowed.
Cold Shut and Laps	None allowed.
Porosity and Inclusions	The maximum diameter shall not exceed 0.02" or 1/3 of T, whichever is the lesser. Indications less than .010" in diameter shall not be considered.
Inadequate Penetration and Incomplete Fusion	The maximum length of any indication shall not exceed 1/3 of the T in any weld length of 6T or less. The minimum distance allowed between adjacent incomplete penetration or fusion indications, is 1/2 the length of the longest adjacent indication.
Undercut and Underbead Concavity	The length of any undercut or underbead concavity indication shall not exceed 15% of the total weld length. The depth of any undercut indication where $T < 0.035"$ , undercut shall not exceed 10% of T. Where T is $\geq 0.035"$ and $\leq 0.09"$ , undercut shall not exceed 15% of T or 0.010", whichever is the lesser. Where $T > 0.09"$ , the depth of undercut shall not exceed 0.015". The minimum distance allowed between adjacent undercut or underbead concavity indications is 1/2 the length of the longest adjacent indication.
Misalignment	Misalignment shall not exceed 15% of T, or 0.025", whichever is the lesser.
Weld Face or Root Concavity or WM Thinning	Thinning shall not exceed 15% of T or 0.015", whichever is the lesser.
Weld Face or Root Convexity	Reinforcement, or melt-thru, shall not exceed 20% of T or 0.06", whichever is the lesser.

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